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(54) **MULTIBAND ANTENNA**

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H01Q 1/52 (2006.01)
H01Q 21/30 (2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 5/50*** (2015.01); ***H01Q 1/523*** (2013.01); ***H01Q 21/30*** (2013.01)

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CPC H01Q 5/50; H01Q 5/42; H01Q 21/30; H01Q 21/08; H01Q 1/523

See application file for complete search history.

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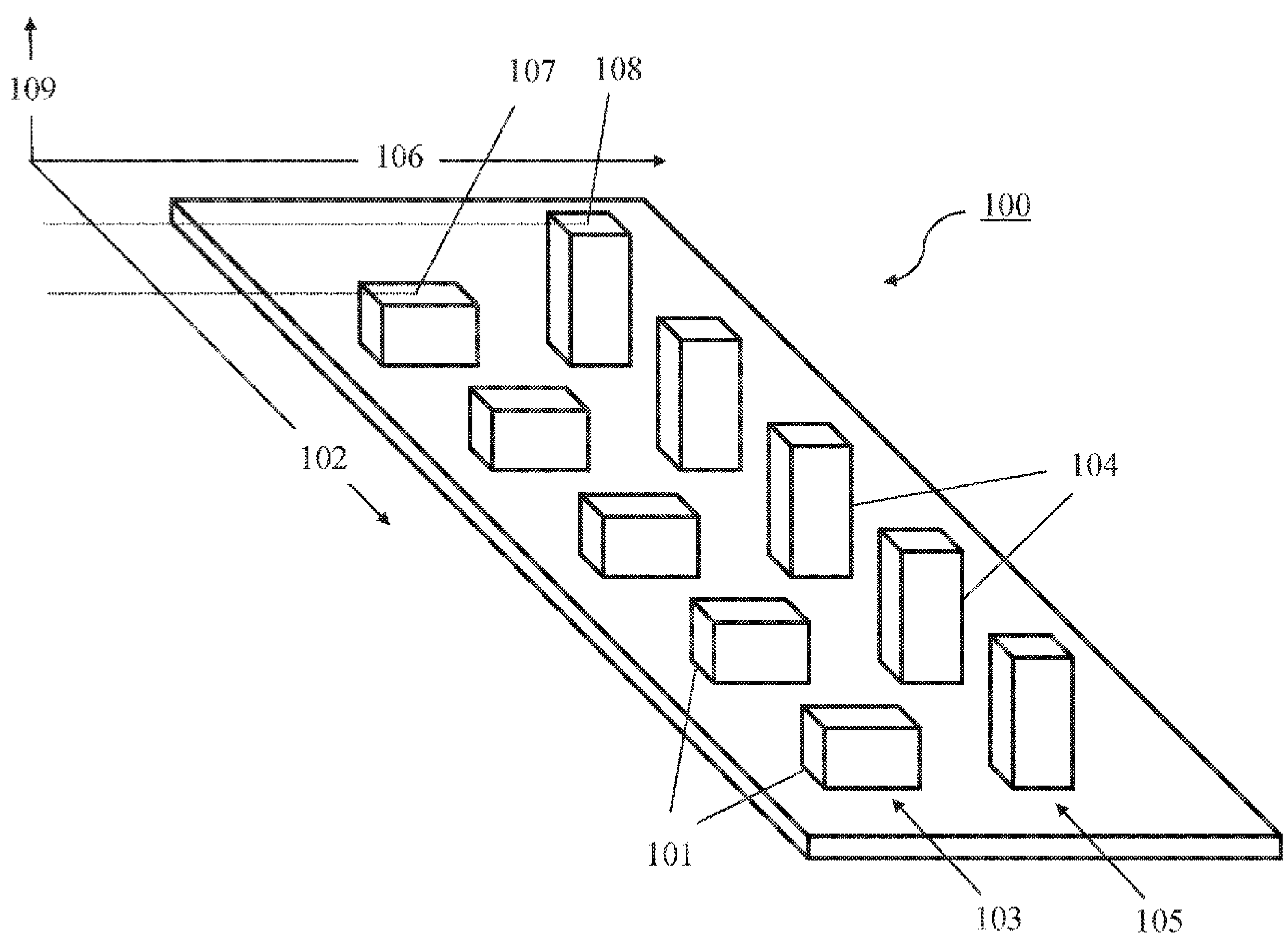
(57) **ABSTRACT**

An antenna has a plurality of first radiating elements configured to radiate in a first frequency band and a plurality of second radiating elements configured to radiate in a second frequency band. The second frequency band at least partially overlaps the first frequency band. The first radiating elements are arranged along the longitudinal direction of the antenna in a first column, and the second radiating elements are arranged along the longitudinal direction of the antenna in a second column. The second column is separated from the first column along a lateral direction of the antenna. Further, feed points of each first radiating element are separated from feed points of each second radiating element along a bore sight direction of the antenna.

17 Claims, 10 Drawing Sheets



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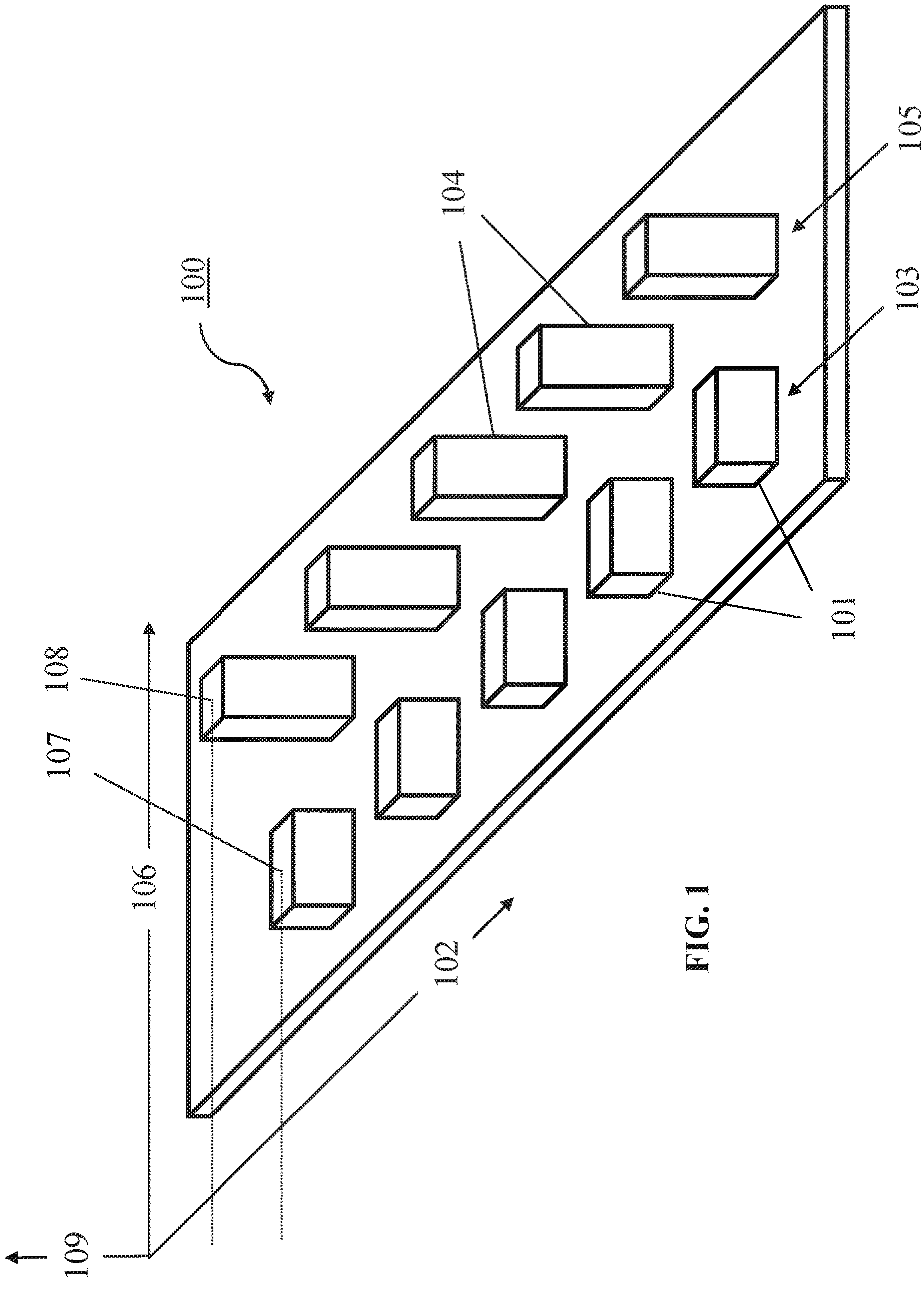

FIG. 1

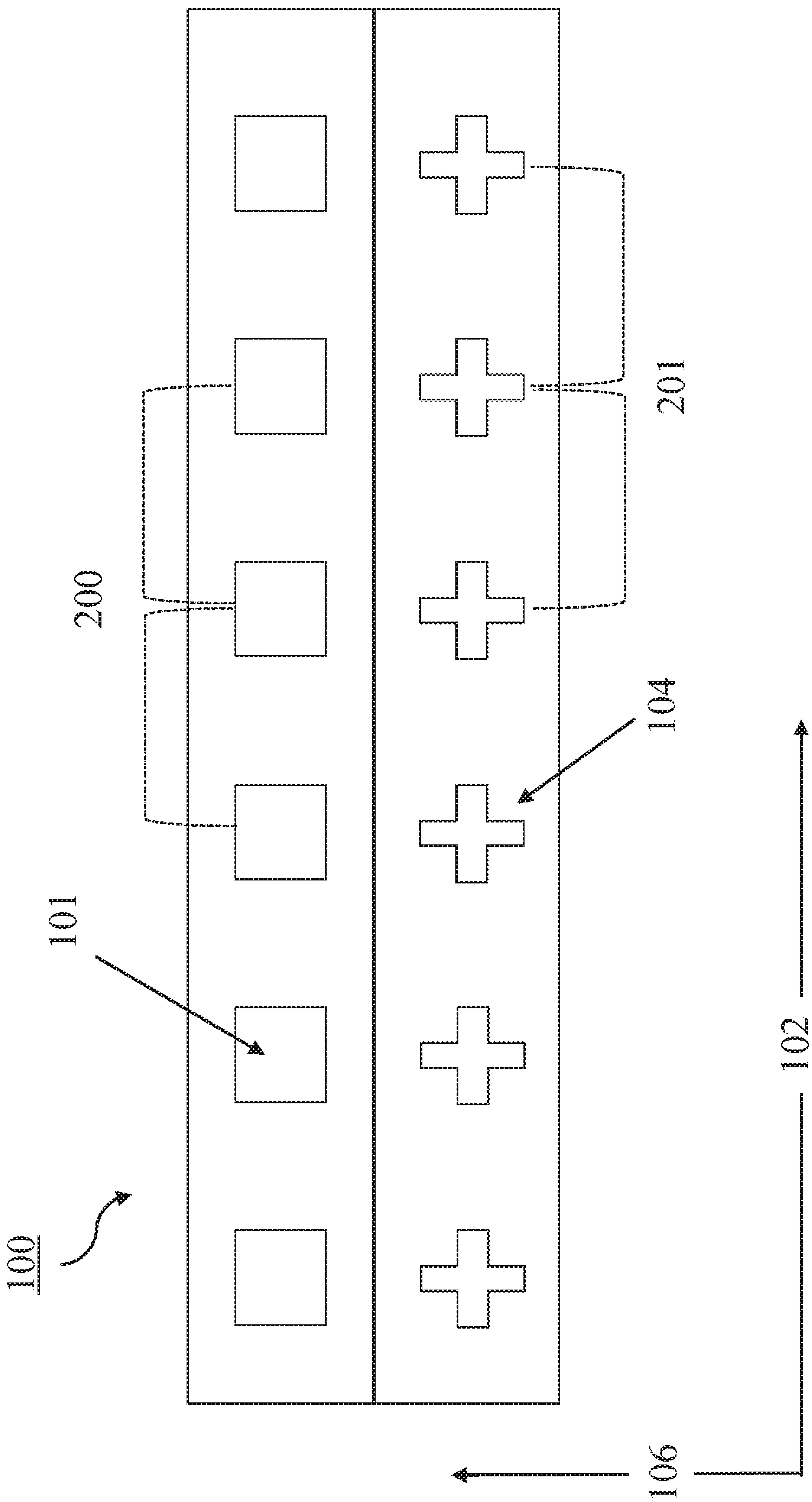

FIG. 2

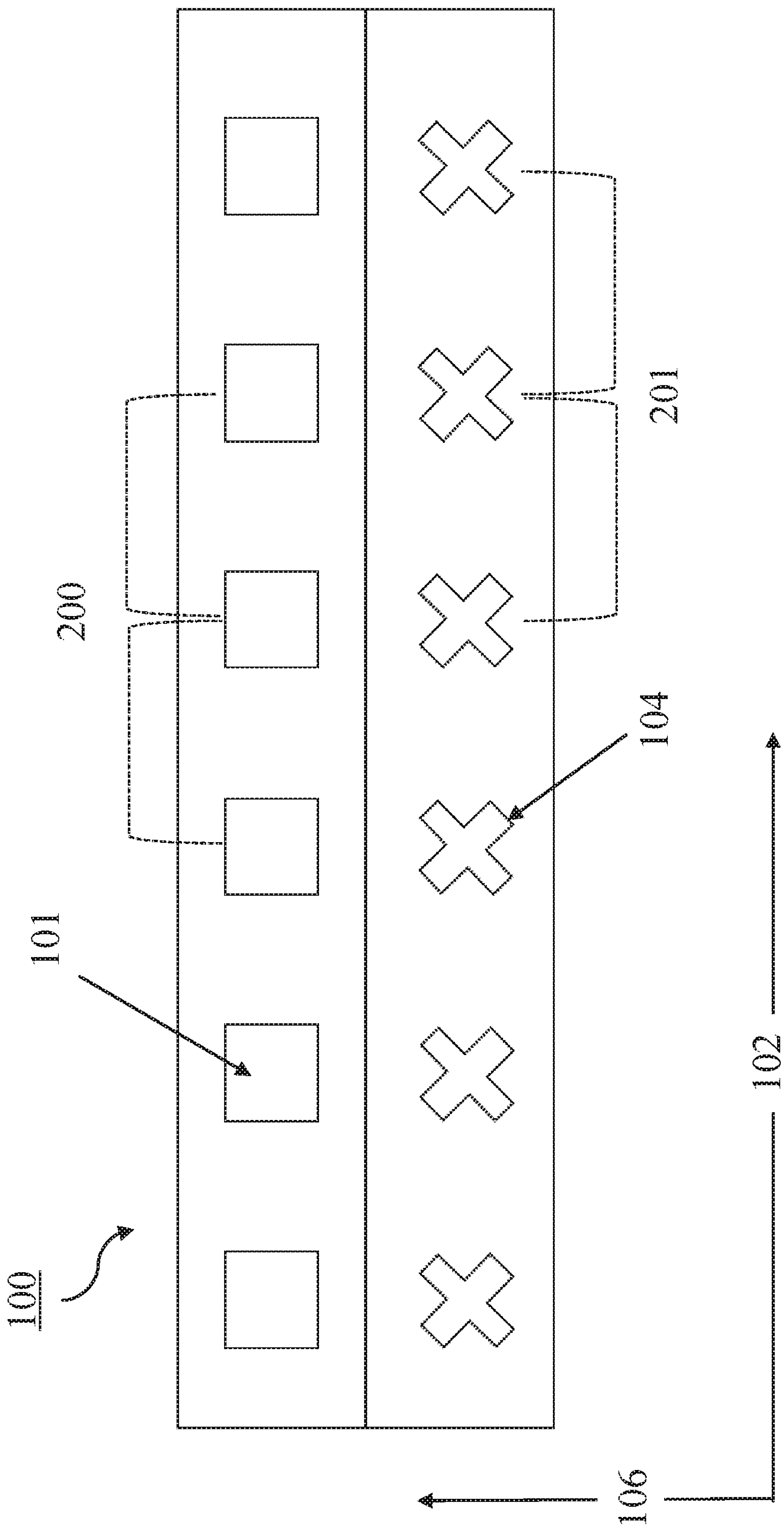

FIG. 3

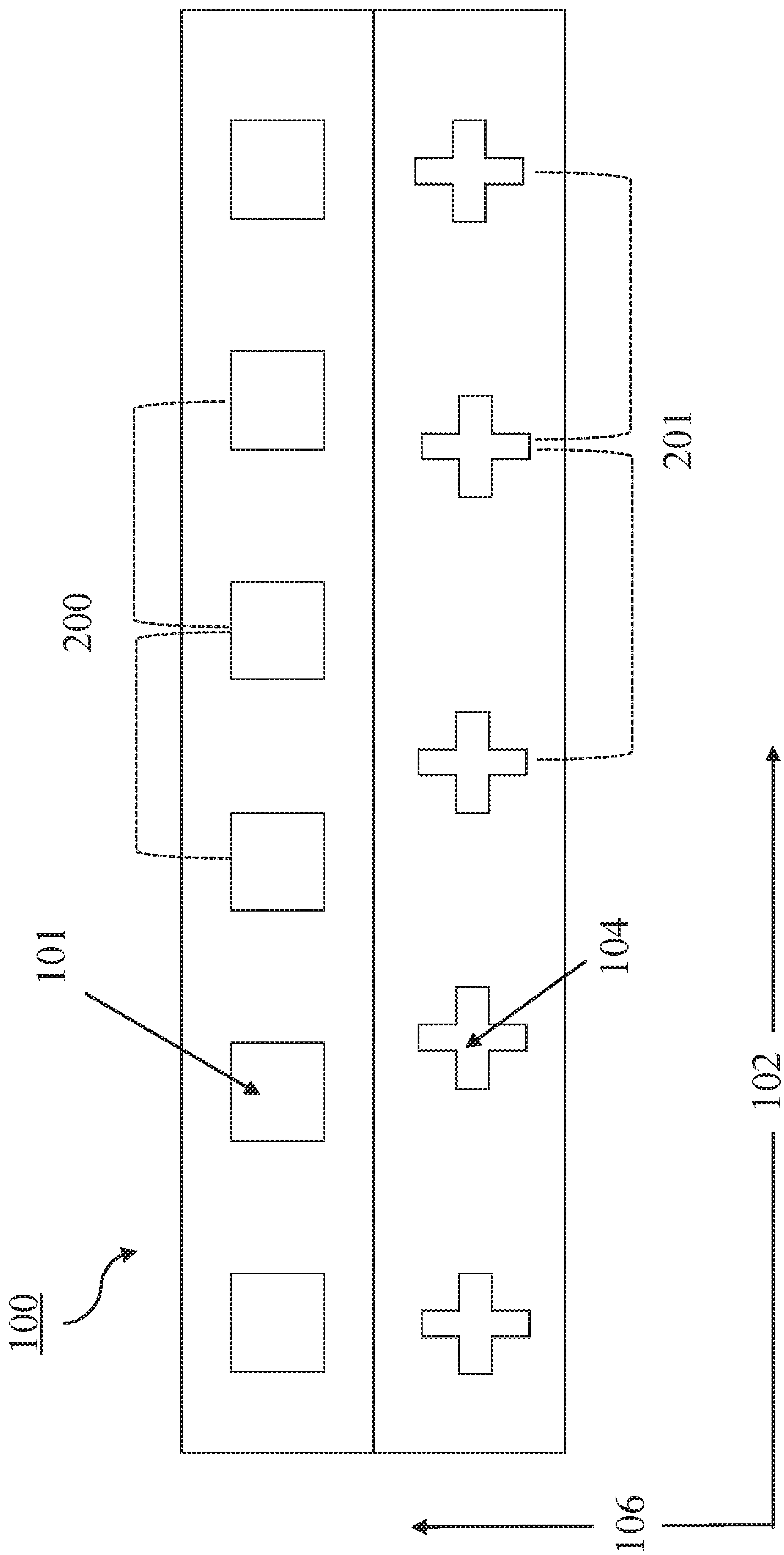

FIG. 4

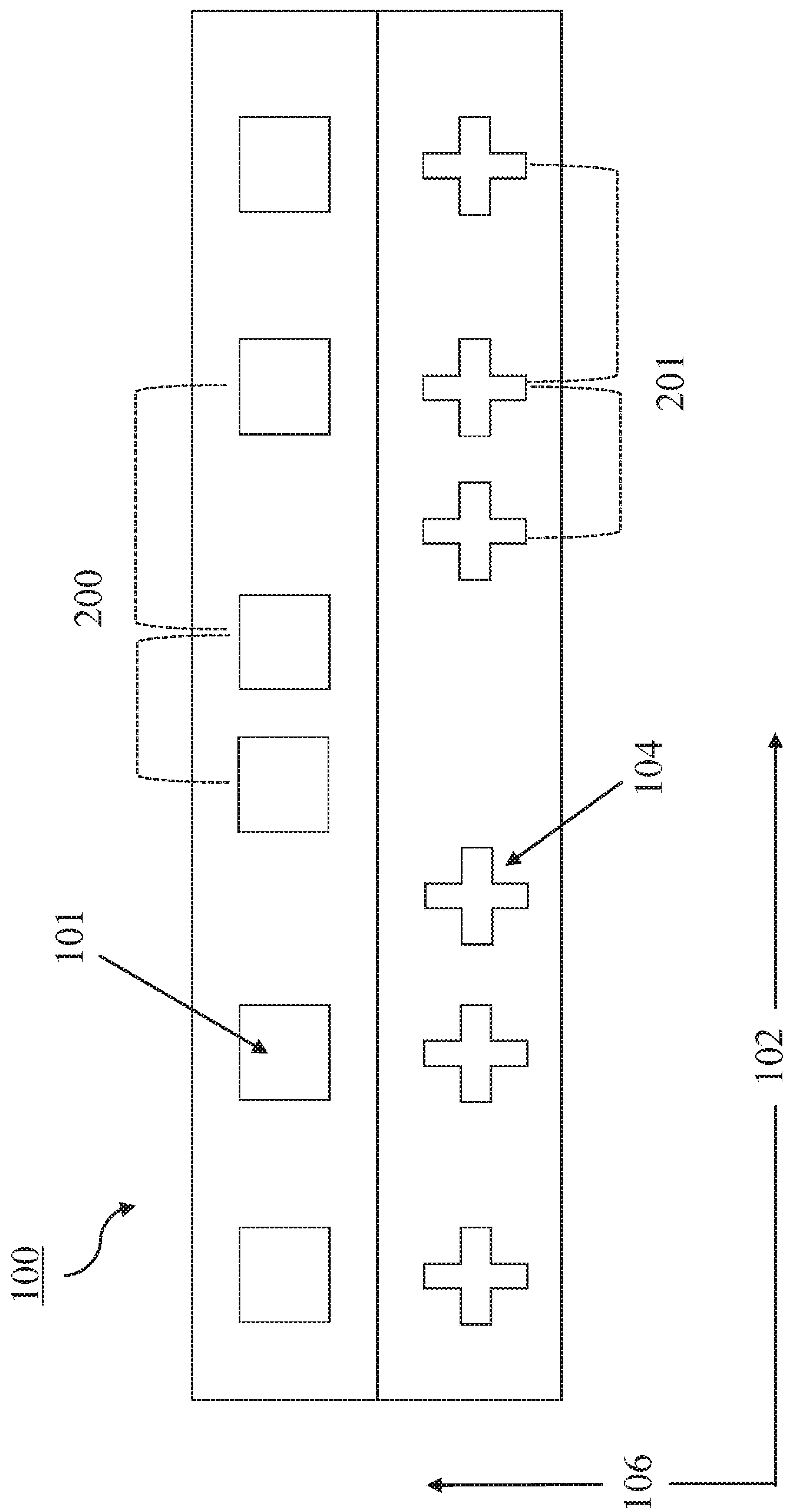

FIG. 5

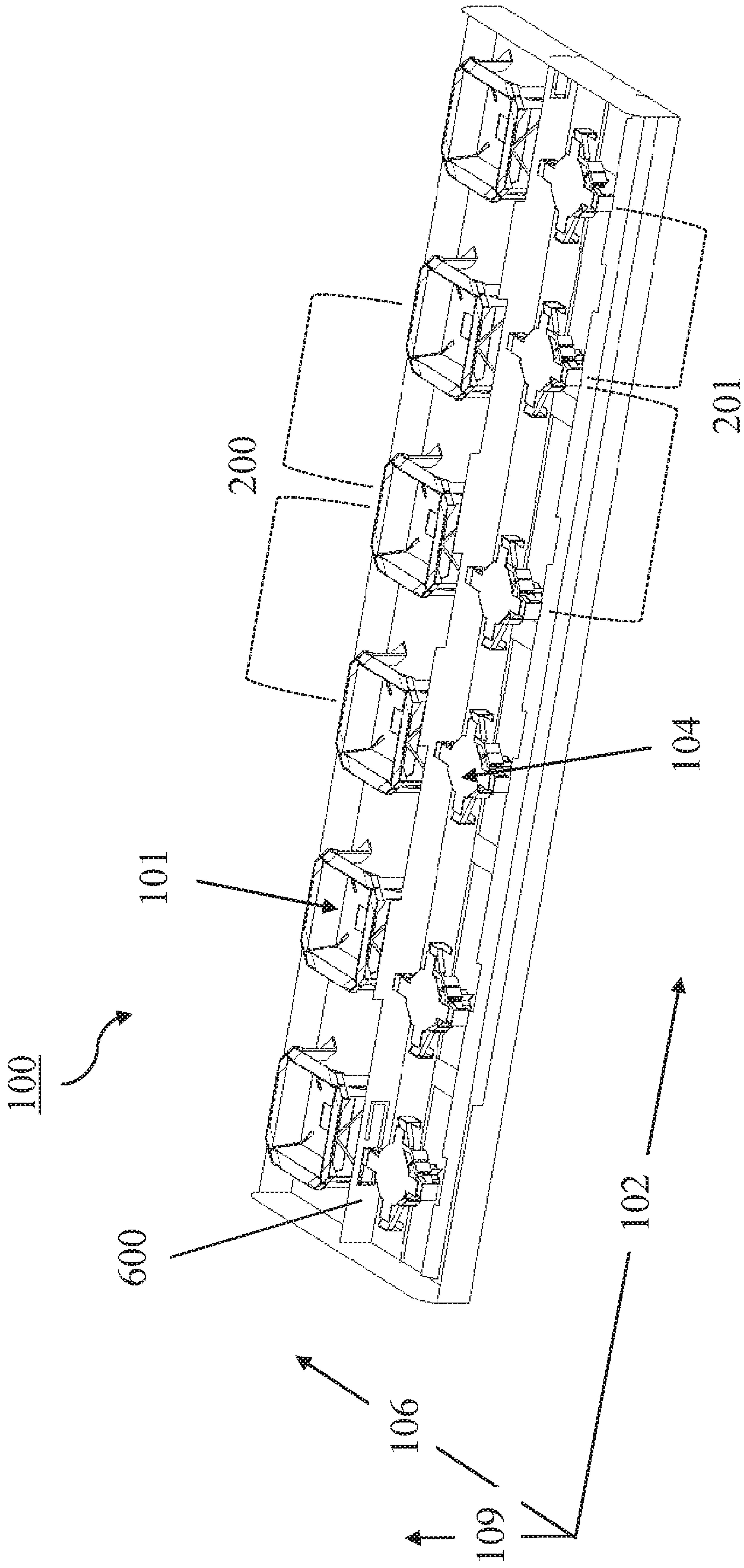

FIG. 6

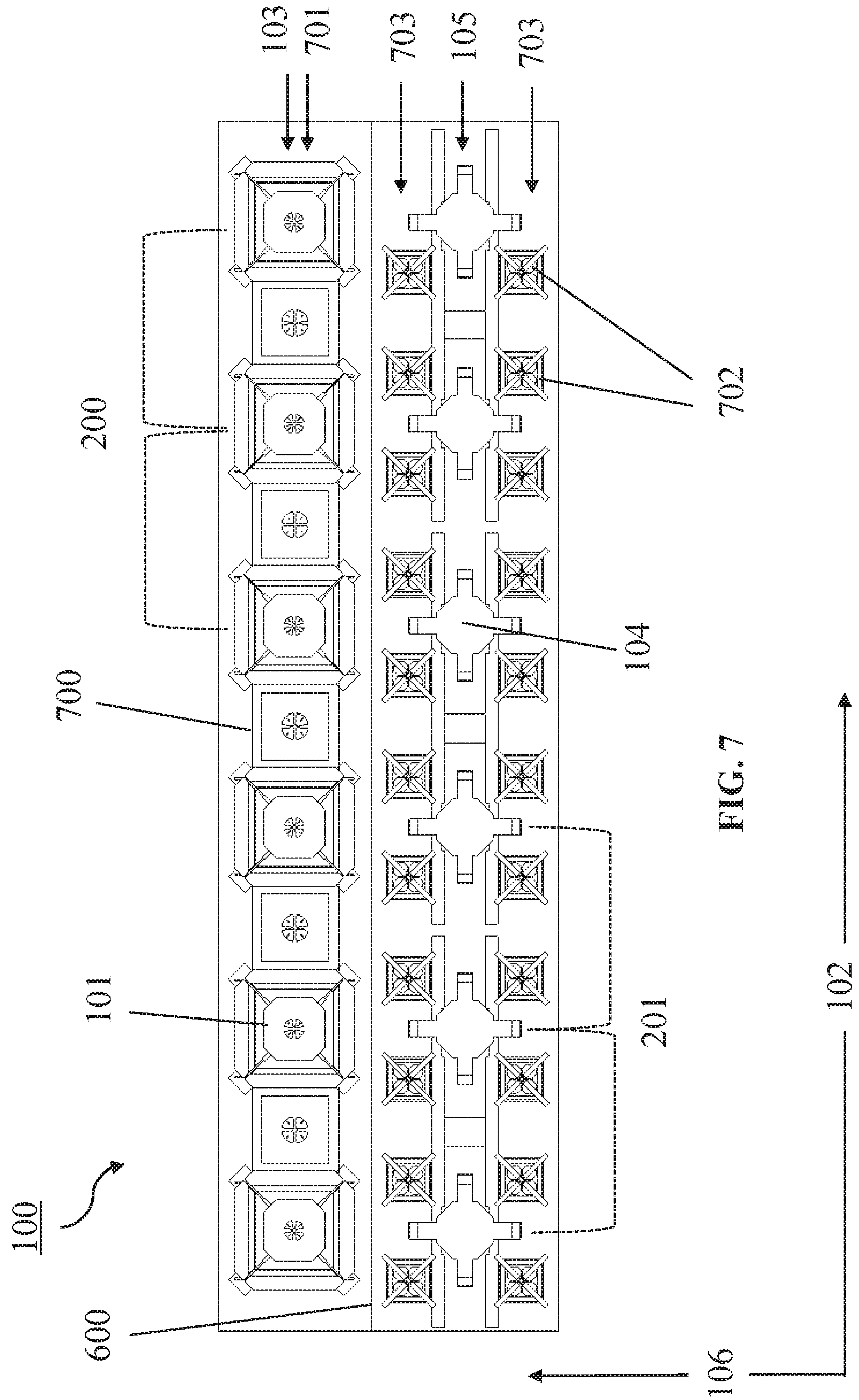

FIG. 7

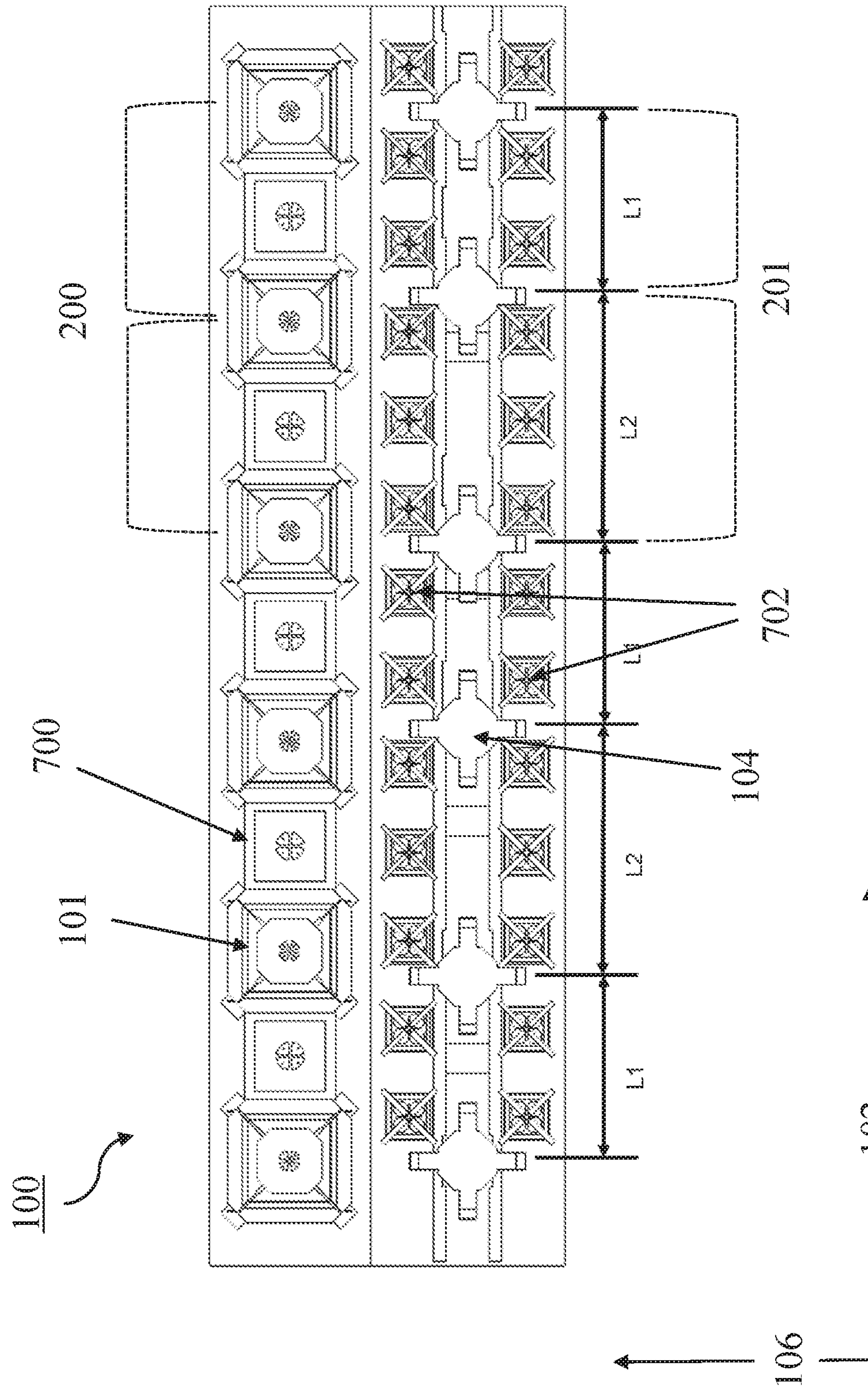

FIG. 8

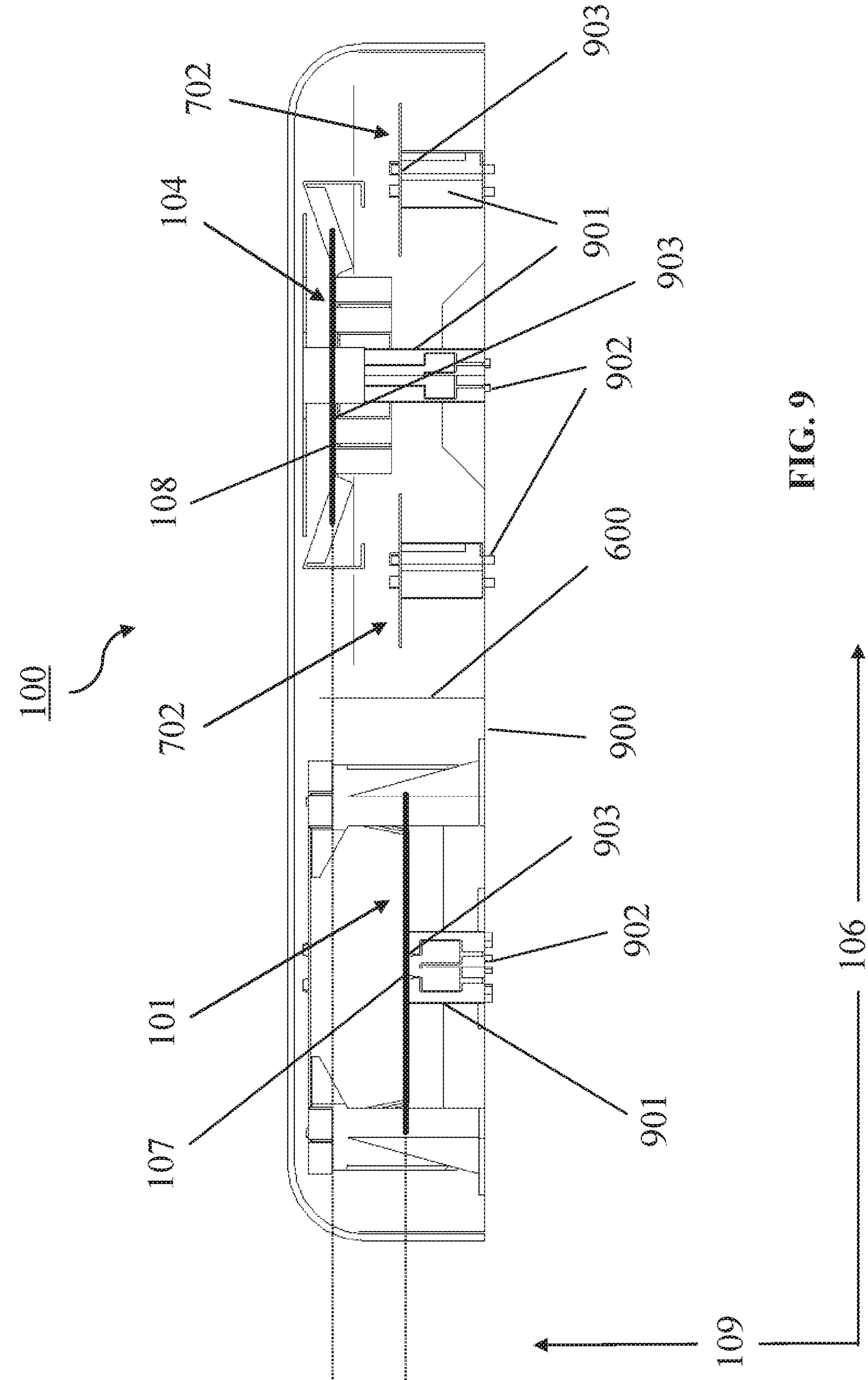
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FIG. 9

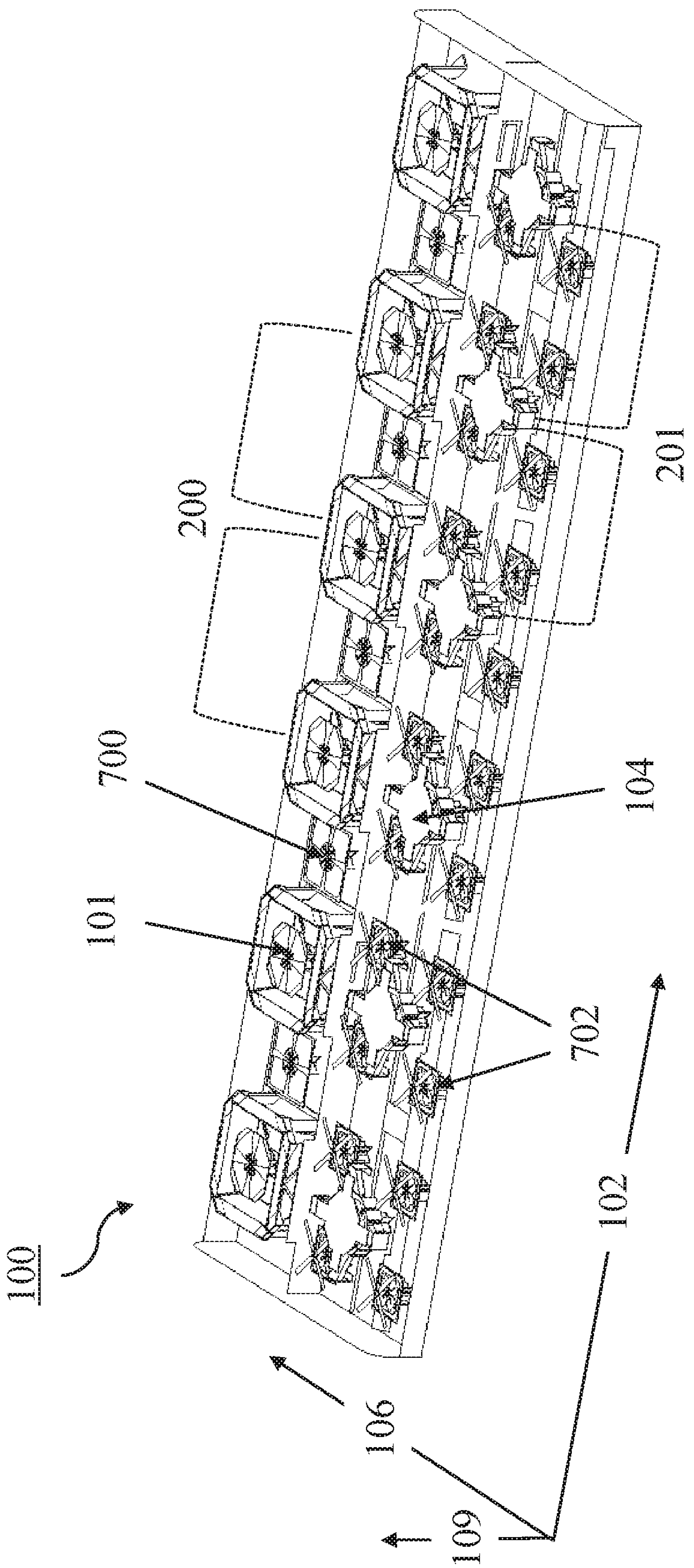

FIG. 10

MULTIBAND ANTENNA

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of International Application No. PCT/EP2017/069811, filed on Aug. 4, 2017, the disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The present invention relates to a multiband antenna.

BACKGROUND

With the deployment of LTE systems, network operators are adding new spectrum to the networks in order to increase the network capacity. Therefore, antenna vendors are requested to develop new antennas that have more ports and/or arrays and support new frequency bands, without increasing the size of conventional antennas.

Especially in order to exploit all capabilities of the LTE standard, new antennas support 4×4 Multiple Input Multiple Output (MIMO), which is particularly useful in higher frequency bands (HB), but is also desired in lower frequency bands (LB) so as to be ready for future deployments. Typical MIMO requirements in current LTE deployments are shown in the below table, where the first column indicates the operating frequency band, and the second column indicates the associated MIMO requirement.

Operating Band	MIMO Requirement
700	2 × 2
800	2 × 2
900	2 × 2
1500 (L-Band)	2 × 2
1800	4 × 4
2100	4 × 4
2600	4 × 4

As a consequence, ports and/or antenna arrays should be duplicated, at least in the higher frequency bands. Notably, apart from the above-mentioned gained MIMO capabilities, an increase of the number of ports would also enable very interesting scenarios, like "site sharing", according to which an antenna is shared between at least two different operators. Site sharing would significantly reduce the operational costs.

New frequency bands, like the supplementary downlink (SDL) or the L-Band (1.427-1.52 GHz) are currently being auctioned, and are already licensed in several countries. Therefore, new antenna architectures should preferably support these new bands.

Additionally, in order to facilitate site acquisition and to fulfill local regulations regarding antenna site upgrades, the width of the new antennas should be comparable to legacy products. Further, to maintain the mechanical support structures currently deployed in the antenna sites, also the wind load of the new antennas should be equivalent to a wind load of conventional antennas. These factors lead to a very strict limitation in height and width of new antennas. However, despite these strict site limitations, and also the desired increase of the band widths and/or the addition of new bands, the Radio Frequency (RF) performance of the new antennas should not be worse than the performance of conventional antennas. This is to at least maintain or even improve the current coverage area and network performance.

The above explanations show that it is a big challenge for antenna designers to find new multiband antenna architectures that: allow increasing the number of ports, allow increasing the operating bandwidth and/or the support of new bands, and allow at least maintaining the same RF performance as before, without compromising on the height and width of the new antennas.

Conventional antennas that combine two LB arrays and three HB arrays are referred to as 2L3H antennas. For instance, it is known to arrange two coaxial arrays (HB/LB) and an additional third array (HB) between the two coaxial arrays. The main disadvantage of this conventional antenna is its width, which is not optimal because the distance between the two LB arrays is relatively big so that not too much shadow is created on the central HB array. In addition, with this conventional antenna it is not possible to dispose a shield wall between the two LB arrays.

In another conventional 2L3H antenna, there is in truth only one LB array in the center of the antenna, which array is divided into two arrays by using duplexers at the element level. The resultant duplexed LB arrays, however, do not work in the full bandwidth, but only in sub-bands thereof. As a consequence, 4×4 MIMO is not possible in the LB of this conventional antenna. Additionally, the duplexers are very complex devices (the guard band is quite small), introduce losses, and significantly increase a passive intermodulation (PIM) risk for the antenna.

SUMMARY

In view of the above-mentioned challenges and disadvantages, the present disclosure provides improved multiband antennas. For example, the present disclosure provides a multiband antenna that allows supporting new frequency bands, while maintaining or even improving RF performance, and while maintaining very strict limitations on the antenna height and antenna width. In particular, at least some embodiments of the disclosure provide a multiband antenna for at least two frequency bands, preferably for even more frequency bands. More particularly, a 2L3H antenna with two LB arrays and three HB arrays is provided by at least some embodiments of the present disclosure, where LB-to-LB coupling is minimized. The width of the 2L3H antenna of embodiments thereby does not exceed 430 mm.

The present disclosure provides a multiband antenna in which the interaction between two different LB arrays of radiating elements is minimized so that the arrays of radiating elements can be arranged closer together.

A first aspect of the present disclosure provides an antenna, the antenna including: a plurality of first radiating elements configured to radiate in a first frequency band, the first radiating elements being arranged along a longitudinal direction of the antenna in a first column; and a plurality of second radiating elements configured to radiate in a second frequency band, the second frequency band at least partially overlapping with the first frequency band, the second radiating elements being arranged along the longitudinal direction of the antenna in a second column. The second column is separated from the first column along a lateral direction of the antenna. Feed points of each first radiating element are separated from feed points of each second radiating element along a bore sight direction of the antenna.

Feed points are the points where the transmission between a feeding network of the antenna and the radiating element happens. The feed points are the designated excitation points of the radiating elements, i.e. are the points at which current is excited into the respective radiating elements.

The longitudinal direction of the antenna corresponds to a vertical extension direction of the antenna, when it is arranged in use on an antenna pole. That means, the antenna is in this case arranged on the pole with one longitudinal end pointing downwards, i.e. towards earth, and the other longitudinal end pointing upwards, i.e. towards the sky. In this use case, the bore sight direction is along the direction facing away from the antenna pole.

Due to the feed points being at different heights (positions in the bore sight direction of the antenna), the coupling between the first radiating elements and the second radiating elements is drastically reduced. This reduction allows the two columns to be placed closer together. For instance, if the first and second column of the antenna provide two LB arrays, e.g. of a 2L3H antenna, the antenna width can be kept at 430 mm or less. Furthermore, the RF performance of the antenna is at least the same as for an antenna having a larger width and having two radiating element columns placed further apart from another.

These small dimensions of the antenna facilitate site acquisition and upgrade, and allow the reuse of existing mechanical support structures, because the wind load of the antenna is equivalent to the wind load of conventional antennas. The antenna can also be provided within an increased number of ports, and is suitable for site sharing, thus reducing significantly the operational costs of network operators.

The first and second radiating elements may respectively operate in, for example, a band between 690-960 MHz, and would in this case be considered to be LB radiating elements. Both the first and second radiating elements may be configured to radiate in the same frequency band, or in two different frequency bands that are overlapping each other.

In an implementation form of the first aspect, a shape and/or type of the first radiating element is different from a shape and/or type of the second radiating element.

In this disclosure the formulation "A and/or B" should be understood as a more compact formulation of "at least one of A or B".

For instance, at least one of the first and second radiating elements may be a radiating element with low profile design, for instance, having only a height of 70 mm, which corresponds to 0.16λ at a frequency of, e.g. 690 MHz, where λ is the wavelength for this frequency.

In a further implementation form of the first aspect, the first radiating elements have a cup shape and the second radiating elements have a cross shape.

Such radiating elements are a preferred solution of the disclosure, since it allows arranging the two columns close together, due to a minimized coupling.

In a further implementation form of the first aspect, the feed points of each first radiating element are distanced differently from the center of the first radiating element than the feed points of each second radiating element from a center of the second radiating element.

Thereby, the coupling between the first and second radiating elements in their respective columns is reduced.

In a further implementation form of the first aspect, the first frequency band and the second frequency band are identical.

As mentioned above, preferably the first and second frequency band may cover at least a frequency range of 690-960 MHz.

In a further implementation form of the first aspect, a spacing of the first radiating elements in the first column and/or a spacing of the second radiating elements in the second column is uniform.

Such a uniform spacing leads to the simplest antenna architecture. It also allows, for instance, the reuse of splitters, and/or the reuse of parts and production process step of conventional antennas.

In a further implementation form of the first aspect, a spacing of the first radiating elements in the first column and/or a spacing of the second radiating elements in the second column is non-uniform.

In a further implementation form of the first aspect, a spacing of the first radiating elements in the first column is different from a spacing of the second radiating elements in the second column.

Such different and/or non-uniform spacing in the first and/or second columns may lead to significant advantages. For instance, strong advantages in terms of coupling at array level are obtained. For the uniform case, the separation in the lateral direction between the individual radiating elements in the first and second columns is the same at every array position. Therefore, also the inter-array coupling (phase and amplitude) is the same. With non-uniform and/or different spacing in the two columns, the separation in the lateral direction may be different at different positions, so that also the coupling will be different (i.e. the amplitude will change, and most importantly the phase of the coupling will be rotated), which leads to an improvement in the coupling at array level. The level of improvement may depend on how non-uniform the spacing is. Big differences in the spacing will bring big improvements and small differences will still bring non-significant improvements.

In a further implementation form of the first aspect, a second column is separated from the first column along the lateral direction of the antenna by 0.40-0.70 times the wavelength at the lowest frequency in the first and/or second frequency band.

In the most preferred implementation, the separation is 0.48λ at the lowest frequency. With such a separation, the proposed architecture reaches very low coupling levels.

In a further implementation form of the first aspect, an isolation wall is placed between the first column and the second column.

The isolation wall (or shield wall) is a possibility—especially when the antenna is a 2L3H antenna—because of the first and second columns of radiating elements and their shapes and arrangements. The isolation wall helps to further significantly reduce the coupling between the two columns. Specifically, the shield wall between the two columns helps to achieve an often required level of isolation of 28 dB or less between the two columns, despite of the tight spacing described in particular with respect to the previous implementation form.

In a further implementation form of the first aspect, the antenna further includes a plurality of third radiating elements configured to radiate in a third frequency band higher than the first frequency band and the second frequency band. The third radiating elements are arranged along the longitudinal direction of the antenna in a third column, and the third column is in-line with the first column.

In a further implementation form of the first aspect, the first column and the third column form together a coaxial array of radiating elements, in which at least some of the first and third radiating elements are arranged interleaved with another and at least some of the first radiating elements embed a third radiating element.

With an antenna according to either one of the two above implementation forms, at least one further frequency band can be added to the antenna, without increasing the width and height of the antenna and without sacrificing on its RF performance.

In a further implementation form of the first aspect, the antenna further includes a plurality of fourth radiating elements configured to radiate in a fourth frequency higher than the first frequency band and the second frequency band. The fourth radiating elements are arranged along the longitudinal direction of the antenna in two fourth columns separated from another along the lateral direction of the antenna, and the fourth columns are arranged parallel to the second column.

In a further implementation form of the first aspect, the second column and the two fourth columns form together a side-by-side array of radiating elements, in which the fourth radiating elements are arranged on either side of the second radiating elements.

The antenna according to either one of the two above implementation forms allows adding a further frequency band without increasing the width and height of the antenna and without sacrificing RF performance. In particular, with the third and fourth radiating elements of the previous implementation forms, a 2L3H antenna may be designed with a total width of only 430 mm and with a RF performance that is the same (or even better) than that of a conventional 2L3H antenna.

In a further implementation form of the first aspect, the third frequency band and the fourth frequency band are identical, partially overlapping, or disjoint.

In particular, the fourth frequency band may be higher than the third frequency band, or also vice versa.

In a further implementation form of the first aspect, the antenna is configured for multiband operation in the two lower first and second frequency bands and the two higher third and fourth frequency bands.

In a further implementation form of the first aspect, the antenna further includes a feedboard, where at least each first and second radiating element includes an intermediate element, the intermediate element having feedboard soldering points soldered to the feedboard and feeding network endpoints for exciting currents into the feed points of the respective radiating elements, and where the feedboard soldering points and the feeding network endpoints are connected.

It has to be noted that all devices, elements, units and means described in the present disclosure could be implemented in the software or hardware elements or any kind of combination thereof. All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. Even if, in the following description of specific embodiments, a specific functionality or step to be performed by external entities is not reflected in the description of a specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective software or hardware elements, or any kind of combination thereof.

BRIEF DESCRIPTION OF DRAWINGS

The above described aspects and implementation forms of the present disclosure will be explained in the following description of embodiments in relation to the enclosed drawings, in which

FIG. **1** shows an antenna according to an embodiment of the present disclosure with two different radiating elements;

FIG. **2** shows an antenna according to an embodiment of the present disclosure with two different radiating elements and uniform spacing;

FIG. **3** shows an antenna according to an embodiment of the present disclosure with two different radiating elements and uniform spacing;

FIG. **4** shows an antenna according to an embodiment of the present disclosure with two different radiating elements and different spacing;

FIG. **5** shows an antenna according to an embodiment of the present disclosure with two different radiating elements and non-uniform spacing;

FIG. **6** shows an embodiment according to the present disclosure with two different radiating elements and with different and non-uniform spacing;

FIG. **7** shows an embodiment according to an embodiment of the present disclosure with four different radiating elements and uniform spacing;

FIG. **8** shows an antenna according to an embodiment of the present disclosure with four different radiating elements and non-uniform spacing;

FIG. **9** shows a cross-section through an antenna according to an embodiment of the present disclosure; and

FIG. **10** shows an antenna according to an embodiment of the present disclosure with four different radiating elements and uniform spacing.

DETAILED DESCRIPTION

FIG. **1** illustrates an antenna **100** according to an embodiment of the present disclosure. The antenna **100** of FIG. **1** is configured to operate in at least two frequency bands.

In particular, the antenna **100** includes a plurality of first radiating elements **101**, which are configured to radiate in a first frequency band, and a plurality of second radiating elements **104**, which are configured to radiate in a second frequency band. The second frequency band is at least partially overlapping with the first frequency band, i.e. the two frequency bands are not disjoint. However, the first frequency band and the second frequency band may be identical, that is completely overlapping. For example, the first and/or second frequency band may be, or at least may cover, the frequency band from 690-960 MHz. Thus, both the first and second radiating elements may each form an LB (Low Band) array.

The first radiating elements **101** are arranged along a longitudinal direction **102** of the antenna **100** in a first column **103**. That is, the first radiating elements **101** form the first column, which column **103** represents an array of radiating elements **101**. The second radiating elements **104** are also arranged along the longitudinal direction **102** of the antenna **100** in a second column **105**. That is, the second radiating elements **104** form the second column **105**, which column **105** represents another array of radiating elements **104**. The two columns **103** and **105** are separated from another along a lateral direction of the antenna **100**. Preferably, the two columns **103** and **105** are parallel in their extension direction along the longitudinal direction **102** of the antenna **100**, i.e. the separation along the longitudinal direction **102** between the two columns **103** and **105** is at least substantially the same at every position along the longitudinal direction **102**. In addition also the extension of the two columns **103**, **105** in the longitudinal direction **102** may be substantially equal. Furthermore, the number of first radiating elements **101** and the number of second radiating elements **104** may be equal.

FIG. **1** shows that the first radiating elements **101** and the second radiating elements **104** are placed at the same positions and have the same spacings with respect to the longitudinal direction **102** of the antenna **100**, which is however only exemplary. Details thereof, and other possibilities for the arrangement of the radiating elements **101**, **104**, will be described below.

The first radiating elements **101** include feed points **107**, and the second radiating element **104** includes feed points **108**. The feed points **107** and **108** are the points, at which current is excited into the respective radiating elements **101**, **104**, in order to cause their radiating. In the antenna **100**, the feed points **107** of each first radiating element **101** are separated from the feed points **108** of each second radiating element **104** along the bore sight direction **109** of the antenna **100**, i.e. along the direction perpendicular to both the lateral direction **106** and the longitudinal direction **102**. In other words the feed points **107** are arranged at a different height than the feed points **108**.

FIG. **2** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. In FIG. **2**, it is highlighted schematically that the first radiating elements **101** are of a different shape and/or type than the second radiating elements **104**. In particular, here the first radiating element **101** are shown to have an exemplary square shape, and the second radiating element **104** are shown to have an exemplary cross shape. In this implementation, the arms of the cross shape are in-line with the lateral and longitudinal directions **106** and **102** of the antenna **100**. Furthermore, FIG. **2** illustrates a spacing **200** between the first radiating elements **101** in the first column **103**, and a spacing **201** between the second radiating element **104** in the second column **105**. Specifically, an exemplary antenna **100** is illustrated in FIG. **2**, in which both spacings **200** and **201** are uniform and are furthermore the same. Moreover, the radiating elements **101** and **104** are arranged at equal positions along the longitudinal direction **102** of the antenna **100**.

FIG. **3** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. Again, the different first radiating elements **101** and second radiating elements **104** are shown. Here the second radiating elements **104** are shown to have a cross shape, but are arranged in a different manner than shown in FIG. **2**. Namely, in this implementation, the second radiating elements **104** are arranged such that the arms of the cross shapes are not aligned with the longitudinal and lateral directions **102** and **106** of the antenna **100**. The first radiating elements **101** are again shown to be square shaped. Further, the spacings **200** and **201** are again uniform and are moreover the same, while the radiating elements **101** and **104** are arranged at equal positions along the longitudinal direction **102**.

FIG. **4** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. FIG. **4** specifically highlights that a spacing **200** of the first radiating elements **101** in the first column **103** is different from a spacing **201** of the second radiating elements **104** in the second column **105**. In particular, the spacing **201** of the second radiating elements **104** is exemplarily shown to be larger than the spacing **200** of the first radiating elements **101**. Accordingly, the first and second radiating elements **101** and **104** are also not placed at identical positions along the longitudinal direction **102** of the antenna **100**. Like in FIG. **2**, the first radiating elements **101** have an exemplary square shape, and the second radiating elements **104** have an exemplary cross shape.

FIG. **5** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. Here in FIG. **5**, it is highlighted that both the spacing **200** of the first radiating elements **101** in the first column **103**, and the spacing **201** of the second radiating elements **104** in the second column **105** are non-uniform. Accordingly, at least some of the first radiating elements **101** are placed along the longitudinal direction **102** of the antenna **100** at positions, at which no second radiating element **104** is placed. Like in FIG. **2**, the first radiating elements **101** have an exemplary square shape, and the second radiating elements **104** have an exemplary cross shape.

Considering the examples of the FIGS. **2** to **5**, it is important to mention that the disclosure is not limited to any specific type and/or shape of the first and/or second radiating elements **101** and/or **104**, but just to the fact that the first radiating elements **101** should be different from the second radiating elements **104**, and that the positions of the feed points **107** and **108** of these radiating elements **101** and **104** are different along the bore sight direction **109** (also designated as height) of the antenna **100**.

Furthermore, the spacings **200** and/or **201** along the longitudinal direction **102** of the antenna **100** may not be the same in both columns **103**, **105**, and may not be uniform either. These features can help to improve (i.e. reduce) the coupling at array level. This is due to different resulting distances between the respective radiating elements **101**, **104** in the different columns **103**, **105**, and of resulting different phases of the coupling between these radiating elements.

FIG. **6** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. FIG. **6** is particularly a perspective view of the antenna **100** and of the first radiating elements **101** in the first column **103** and the second radiating elements **104** in the second column **105**. Here in FIG. **6**, the spacing **200** between the first radiating elements **101** is exemplarily uniform, whereas the spacing **201** between the second radiating elements **104** is exemplarily non-uniform.

In FIG. **6**, it can also be well seen that an isolation wall **600** may be placed between the first column **103** and the second column **105**, i.e. between the first radiating elements **101** and the second radiating elements **104**. This measure reduces even further the coupling between these two arrays (columns) of different radiating elements **101**, **104**.

FIG. **7** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** of FIG. **1**. In particular, FIG. **7** shows an antenna **100** with a 2L3H architecture in a top view. The antenna **100** includes the first radiating elements **101** arranged in the first column **103**, and the second radiating element **104** arranged in the second column **105**. Here in FIG. **7**, exemplarily, the spacing **200** between the first radiating elements **101** is uniform and is the same as the also uniform spacing **201** between the second radiating elements **104**.

Further, the antenna **100** includes a plurality of third radiating elements **700**, which are arranged along the longitudinal direction **102** of the antenna **100** in a third column **701**. The third column **701** is thereby in-line with the first column **103**. In particular, this in-line positioning of the columns **103**, **701** is achieved by arranging the third radiating elements **700** interleaved with the first radiating elements **101**, where at least some of the first radiating elements **101** embed a third radiating element **701** in between.

Accordingly, the first column **103** and the third column **701** form together a coaxial array of radiating elements **101** and **700**.

Further, the antenna **100** includes a plurality of fourth radiating elements **702** arranged along the longitudinal direction **102** of the antenna **100** in two fourth columns **703**. These two fourth columns **703** are separated from another along the lateral direction **106** of the antenna **100**. Further, the two fourth columns **703** are preferably arranged parallel to the second column **105**, and are accordingly parallel to another. Since the fourth radiating elements **702** are arranged on either side of the second radiating elements **104**, the second column **105** and the two fourth columns **703** form together a side-by-side array of radiating elements **104** and **702**.

That is, the antenna **100** of FIG. **7** combines a coaxial array with a side-by-side array of radiating elements. Preferably, the first radiating element **101** and the second radiating element **104** are both LB radiating elements, i.e. the first frequency band and the second frequency band are lower than the third and the fourth frequency band. Accordingly, the third and fourth radiating elements **700** and **702** may be considered high-band (HB) radiating elements. For instance, they may cover a third frequency band that spans 1427-2200 MHz (third radiating elements **700**), and/or a fourth frequency band that spans 1710-2690 MHz (fourth radiating elements **702**).

The antenna **100** shown in FIG. **7** can be deployed with a total width of only 430 mm. At the lowest frequency, which is preferably 690 MHz for the LB bands (e.g. 690-960 MHz), the width of 430 mm corresponds to less than 1λ. With the additional shield wall **600** placed between the first **103** and second column **105**, and accordingly also between the third column **701** and the fourth column **703**, an isolation level between the LB arrays (i.e. the first and second columns) can be as low as 28 dB. Accordingly, it is possible with the antenna **100** of FIG. **7** to provide two arrays with **650** beam width and 28 dB coupling in a width of less than 1λ. This is conventionally not possible or at least very difficult to achieve.

FIG. **8** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** in the FIGS. **1** and **7**. In FIG. **8** the spacing **201** between the second radiating elements **104** in the second column **105** is non-uniform. Also the spacing between the two side-by-side columns **703** of the fourth radiating elements **702** is non-uniform. That is, in the side-by-side array, the spacing is non-uniform in both LB and HB. As can be seen, there are alternatively placed either two or three fourth radiating elements **702** between the second radiating elements **104** along the longitudinal direction **102** of the antenna **100**. This helps reducing the average spacing in the fourth column, and therefore reducing the level of the grating lobe in the vertical pattern for larger down tilts of the antenna **100**.

For example, the most common case in current base station antennas, with the LB going from 690-960 MHz, and the HB going from 1710-2690 MHz, uniform vertical spacing of 250/125 mm is the most common approach. This spacing is somehow established in the industry, but has a very strong drawback in terms of grating lobe at a down tilt of 12° and at 2690 MHz. With the architecture of the antenna **100** of FIG. **8**, the level of the grating lobe can be significantly reduced.

In addition, having the non-uniform spacing also between the second radiating elements **104** can mean a strong advantage in terms of coupling at array level. In the uniform case shown e.g. in FIG. **7**, the separation of the first and second radiating elements **101** and **104** along the lateral direction **106** of the antenna **100** is the same at every position, and therefore the coupling (phase and amplitude) is also the same. When all the individual couplings are combined to get the array-to-array coupling, the result is the same as the individual couplings (i.e. it is just an average of several times the same). However, if the spacing along the longitudinal direction **102** of the antenna **100** is different in the first and second columns **103** and **105**, the separation along the lateral direction **106** of the antenna **100** between the first and second radiating elements **101** and **104** will be different at every position in the arrays along the lateral direction **102**. Since the separation is different, the coupling will also be different (the amplitude will change and most importantly, the phase of the coupling will be rotated). In this case, when all the individual couplings are combined to get the coupling at array level, it is not an average of the same, but of different curves with different phases that will be combined, achieving an improvement in the coupling at array level.

FIG. **9** shows an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** shown in the previous figures. FIG. **9** in particular shows a cross-section through the antenna **100**, and thereby shows the antenna **100** along the lateral direction **106** and the bore sight direction **109**, respectively. On the left side of the antenna **100** in FIG. **9** is placed a first radiating element **101** comprising feed points **107** that are positioned differently along the bore sight direction **109** of the antenna **100** than feed points **108** of a second radiating element **104** placed on the right side of the antenna **100** in FIG. **9**. In particular, any feed points **108** of the second radiating element **104** are positioned higher in FIG. **9** than any feed points **107** of the first radiating element **101**. Here in FIG. **9**, the height of the illustrated antenna **100** corresponds to the bore sight direction **109**, as indicated by the coordinate system.

FIG. **9** also shows two fourth radiating elements **702**, which are however only shown exemplarily and are optional elements. Optionally, the antenna **100** has also a plurality of the above-described third radiating elements **700**.

In addition, FIG. **9** shows that the antenna **100** may also include a feedboard **900**, on which the respective radiating elements are provided. At least each first and second radiating element **101**, **104** of the antenna **100** includes such an intermediate element **901**, like a Printed Circuit Board (PCB). The intermediate element **901** has feedboard soldering points **902** for soldering to the feedboard **900**, and has feeding network end points **903** for exciting currents into the feed points **107**, **108** of the radiating elements **101**, **104**, respectively. It can be seen that the feedboard soldering points **902** and the feeding network endpoints **903** are connected e.g. by transmission lines on the intermediate element **901**. They may either be directly connected, or may be connected indirectly, for instance, via a power splitter arranged in between. Notably, the intermediate elements **901** also act as a spacer between the feedboard **900** and the radiating part of the radiating elements **101**, **104**.

FIG. **10** shows in a perspective view an antenna **100** according to an embodiment of the present disclosure, which builds on the antenna **100** shown in FIG. **1**. The antenna **100** includes first radiating elements **101** in a first column **103** with a uniform spacing **200**, and second radiating elements **104** in a second column **105** with an identical uniform spacing **201**. The antenna **100** also includes third radiating elements **700** provided in a column **701** that is in-line with the column of first radiating elements **101**, and fourth radiating elements **104** that are provided side-by-side the second radiating elements **104**.

In summary, embodiments of the disclosure provide an antenna **100** with a new architecture with significantly reduced coupling between two arrays of radiating elements **101** and **104**, namely the first column **103** and the second column **105**. Preferably, these columns **101**, **104** are LB arrays of a 2L3H antenna. For such a 2L3H antenna, in particular the combination of a coaxial array and a side-by-side array leads to a very compact form factor with a width of not more than 430 mm, while the isolation between the LB arrays is below 28 dB and the RF performance is at least as good as in a conventional antenna. The coupling can particularly be minimized due to the different arrangements of the feed points **107**, **108** along the bore sight direction **109**, and further improved by different locations and distances of the feed points **107**, **108** from the respective centers of the radiating elements **101**. In addition, carefully chosen spacings, e.g. non-uniform and different, in the two LB arrays, low profile designs of the individual radiating elements **101**, **104**, and the provision of a shield wall **600** between the first column **103** and second column **105** reduce the coupling even further.

The present invention has been described in conjunction with various embodiments as examples as well as implementations. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the independent claims. In the claims as well as in the description the word "comprising" does not exclude other elements or steps and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

What is claimed is:

1. An antenna comprising:

a plurality of first radiating elements configured to radiate in a first frequency band, the first radiating elements being arranged along a longitudinal direction of the antenna in a first column; and

a plurality of second radiating elements configured to radiate in a second frequency band, the second frequency band at least partially overlapping with the first frequency band,

wherein the second radiating elements are arranged along the longitudinal direction of the antenna in a second column,

wherein the second column is separated from the first column along a lateral direction of the antenna, and

wherein feed points of the first radiating elements are separated from feed points of the second radiating elements along a bore sight direction of the antenna.

2. The antenna according to claim **1**, further comprising

a shape and/or type of the first radiating elements being different from a shape and/or type of the second radiating elements.

3. The antenna according to claim **1**, wherein

the first radiating elements have a cup shape and the second radiating elements have a cross shape.

4. The antenna according to claim **1**, wherein

each of the feed points of the first radiating elements are distanced differently from a respective center of the associated one of the first radiating elements than each of the feed points of the second radiating elements from a respective center of the associated one of the second radiating elements.

5. The antenna according to claim **1**, wherein

the first frequency band and the second frequency band are identical.

6. The antenna according to claim **1**, further comprising:

a spacing of the first radiating elements in the first column and/or a spacing of the second radiating elements in the second column being uniform.

7. The antenna according to claim **1**, further comprising

a spacing of the first radiating elements in the first column and/or a spacing of the second radiating elements in the second column being non-uniform.

8. The according to claim **6**, wherein

the spacing of the first radiating elements in the first column is different from the spacing of the second radiating elements in the second column.

9. The antenna according to claim **1**, wherein

the second column is separated from the first column along the lateral direction by 0.40-0.70 times a wavelength at a lowest frequency in the first frequency band and/or second the frequency band.

10. The antenna according to claim **1** further comprising:

an isolation wall between the first column and the second column.

11. The antenna according to claim **1** further comprising:

a plurality of third radiating elements configured to radiate in a third frequency band higher than the first frequency band and the second frequency band,

wherein the third radiating elements are arranged along the longitudinal direction in a third column and the third column is parallel with the first column.

12. The antenna according to claim **11**, wherein

the first column and the third column together form a coaxial array of radiating elements, in which at least some of the first radiating elements and the third radiating elements are interleaved with another and at least some of the first radiating elements embed one of the third radiating elements.

13. The antenna according to claim **1** further comprising:

a plurality of fourth radiating elements configured to radiate in a fourth frequency band higher than the first frequency band and the second frequency band,

wherein the fourth radiating elements are arranged along the longitudinal direction in two fourth columns separated from another along the lateral direction, and the fourth columns are arranged parallel to the second column.

14. The antenna according to claim **13**, wherein

the second column and the two fourth columns together form a side-by-side array of radiating elements, in which the fourth radiating elements are arranged on either side of the second radiating elements.

15. The antenna according to claim **13**, wherein

a third frequency band and the fourth frequency band are identical, are partially overlapping, or are disjoint.

16. The antenna according to claim **13**, wherein

the first frequency band and the second frequency band comprise two lower frequency bands,

wherein a third frequency band and the fourth frequency band comprise two higher frequency bands, and

the antenna is configured for multiband operation in the two lower frequency bands and the two higher frequency bands.

17. The antenna according to claim **1** further comprising:

a feedboard,

wherein each one of the first radiating elements and the second radiating elements comprises an intermediate element, the respective intermediate element having a respective feedboard soldering point soldered to the feedboard and a respective feeding network endpoint for exciting currents into a respective feed point of the feed points, and

wherein, for each of the first radiating elements and the second radiating elements, the respective feedboard soldering point and the respective feeding network endpoint are connected.

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